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The Dimensional Stability of Lightly-Loaded Epoxy Joints

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Abstract

The use of adhesives to bond metal mounting structures to optical components can significantly simplify the design of an optical system. In precision applications, dimensional instability of the adhesive must be included as a component of the overall error budget. This paper describes the qualification testing of a balanced heterodyne interferometer system in a carefully controlled environment for the purpose of measuring joint stability. Results of this qualification test are reported.

Introduction

Advanced imaging systems, such as those required by extreme ultraviolet lithography require optics figured with subnanometer accuracy over large apertures and must be accurately located within a few nanometers. The preservation of the surface figure and the dimensional stability of the optic's surface relative to the other optics dominate the performance requirements of the optic's mounts.

One concern when using an epoxy in such applications is its long-term stability along the optical axis (shear microcreep). The long-term error budgets for epoxy creep must be kept to a small portion of the total error budget, which may be on the order of 1 micron for each optic. To measure the creep rate of the epoxy, a high-resolution displacement measuring interferometer mounted in a temperature controlled chamber is used to measure the creep of a lightly loaded epoxy joint. In order to verify that the inherent system stability is adequate, a balanced arm heterodyne interferometer has been constructed and used to determine a lower bound on the uncertainty of the creep measurement. The experimental setup, environmental control, and preliminary results are described in this paper. Ultimately, it is desired to demonstrate the sensitivity required for monitoring test samples for short periods of time, spanning many days, or possibly weeks, to establish an estimate of long term creep rates.

Experimental Setup

The setup used for determining the base stability of the system is a four-pass plane mirror interferometer. Figure 1 shows a schematic of the optical arrangement.

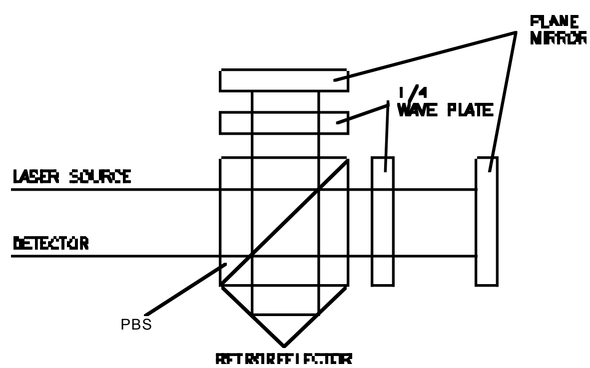

Figure 1: Optical Schematic of the Interferometer

It consists of nominally identical tubular aluminum spacers in each arm that support the plane mirror at a nominally fixed distance from the polarizing beamsplitter (PBS). The spacer is mounted to the body of the PBS using a semi-kinematic three-point contact. The mirror is a $\lambda/10$ aluminized low expansion two-phase glass ceramic optical flat which is mounted using a semi-kinematic three-point mount that contacts the face of the mirror. The spacers are attached to the PBS body with spring-loaded threaded fasteners in order to provide a constant-force joint. Belleville washers provide the spring preload. The retroreflector is similarly attached. The mirror is preloaded against its three-point mount by a leaf spring. To minimize the influence of air property changes during the measurement, care has been taken during assembly to ensure that the optical path difference between the two legs of the interferometer is less than 20 microns. The squareness of the faces of the PBS to which the spacers attach is carefully controlled along with the parallelism of the mirror faces to the mounting flanges of the spacers in order to minimize errors due to beam shear. Figure 2 shows the various components in the assembly.

Figure 2: Interferometer Assembly Components

Measurement Method

The interferometer is mounted to a large aluminum block and placed in a precision temperature control chamber. The chamber temperature control consists of a chiller heat exchanger followed by an electric reheat coil.

The chiller evaporator coils are controlled by a thermostatic valve mounted directly to the evaporator coils. Precision temperature control is achieved by using three cascaded control loops to drive the reheat coils. Feedforward from the chiller control to the reheat coils is also included to increase rejection of variations in the chiller performance. Each temperature feedback loop uses a precision glass bead thermistor. We have shown previously that these thermistors are stable at the millidegree level over times greater than those involved with the creep measurement [1].

The temperature control chamber typically maintains short-term fluctuations below 6 mK and long term variations within a ±1 mK band at the table in the vicinity of the interferometer. The interferometer phase interpolation electronics are also mounted in the chamber. Temperature control at the electronics is typically ±12 mK, with most of the variation due to a diurnal cycling of the power line voltage and the consequent variation in heat dissipation.

During measurements, in addition to the air temperature, both the temperature of the interferometer body and the atmospheric pressure in the chamber are monitored. Some measurement bias may be removed by fitting the dimensional data to temperature and pressure values. Since the observed temperature and pressure variations over the length of several days of measurement contain fluctuations that are significantly larger than their long term trends, fitting and subsequently removing small residual pressure and temperature effects does not appreciably increase the uncertainty of the creep measurement.

Measurement Results

Figure 3 depicts the observed dimensional change of the reference interferometer assembly. After an initial settling period following the closure of the temperature control chamber, the reference interferometer position is asymptotic to a line with a slope of 0.4 nm/day. This value is taken as a lower bound on the uncertainty of creep measurement.

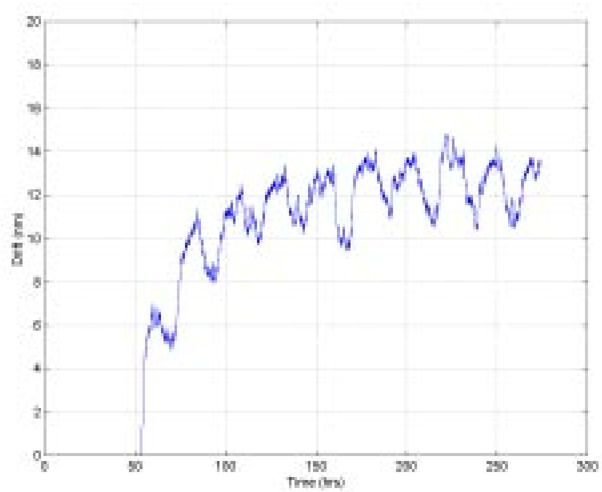

Figure 3: Interferometer Stability Results

Future Work

A small-scale optic mount sample has been designed to hold the optic in a configuration similar to the actual optic mount. A photo of the sample is shown in Figure 4. The mount is made from superinvar and the optic bonded to the mount is made from low expansion two-phase glass ceramic. Superinvar has been chosen as the material for a significant portion of the structure of the metrology loop in order to reduce the temperature susceptibility of the experiment. The contribution of the superinvar to the stability of the interferometer has been budgeted based on previous stability analysis of superinvar [2]. In addition, the combination of low expansion glass ceramic and superinvar mimics the combination of materials in a typical epoxy joint. The bottom side of the optic is lapped to $\lambda/20$ flatness (peak-to-valley) and coated with a thin layer of aluminum. While the thickness of the epoxy bond line in the actual mount is approximately 75 μm, an epoxy bond line of 250 μm is used in the test samples to magnify the effects of creep for the purposes of experimentation. The samples are mounted such that the mirror surface of the optic is parallel to the mating surface of the mount to less than 15 microns. A pair of these samples will be used to evaluate the stability in the unloaded condition.

A second set of samples to which a load can be applied has also been designed. The loading mechanism is designed to load the epoxy joint in one arm in shear by pulling on it and in the other arm by pushing on it. This effectively doubles the sensitivity of the system.

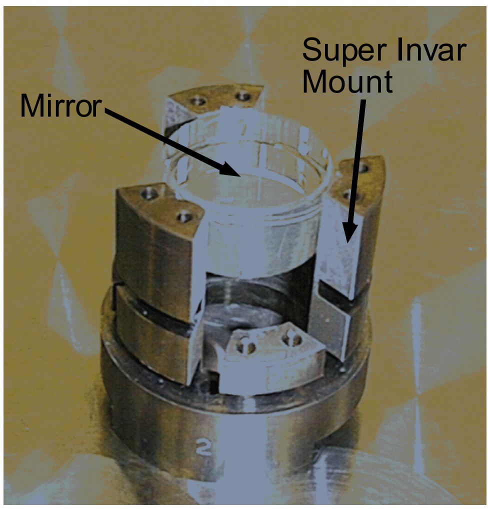

Figure 4: Epoxy Creep Samples

Conclusions

A balanced and temperature controlled plane mirror interferometric dilatometer has been constructed and used to qualify an interferometric measurement process at levels commensurate with its intended use for the measurement of the stability of epoxy joints. Stability better than 0.4 nm/day has been demonstrated. The dilatometer is capable of measuring shear deformation of both loaded and unloaded epoxy joints

References

[1] Lawton, K. M., and Patterson, S. R., "Evaluation of Thermistors as a Reference for Local Temperature Control," *Proceedings of the 12th Annual ASPE Conference*, Norfolk, VA, 149-152(1997).

[2] Patterson, S. R., "Interferometric Measurement of the Dimensional Stability of Superinvar," *Lawrence Livermore National Laboratory UCRL-53787*, 1988.

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